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SPATIAL ABILITY AS A PREDICTOR OF
FLIGHT TRAINING PERFORMANCE

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July 1987

Interim Technical Paper for Period January 1982 - September 1986

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFHRL-TP-86-70	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Manpower and Personnel Division 6b. OFFICE SYMBOL (If applicable) AFHRL/MOEA	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Air Force Human Resources Laboratory Brooks Air Force Base, Texas 78235-5601	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Air Force Human Resources Laboratory 8b. OFFICE SYMBOL (If applicable) HQ AFHRL	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Brooks Air Force Base, Texas 78235-5601	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62703 · PROJECT NO. 7719 · TASK NO. 18 · WORK UNIT ACCESSION NO. 45

11. TITLE (Include Security Classification)
Spatial Ability as a Predictor of Flight Training Performance

12. PERSONAL AUTHOR(S)
Carretta, T.R.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Interim	FROM Jan 82 TO Sep 86	July 1987	16

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
05	09	
05	08	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Air Force Officer Qualifying Test (AFOQT); Basic Attributes Tests (BAT); cognitive/perceptual abilities; flight training performance; Mental Rotation Test; pilot selection; spatial ability.

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Spatial ability has been demonstrated to be related to performance of a variety of tasks including several military enlisted jobs and piloting aircraft. This paper examined the relationship between performance on a spatial-ability task (i.e., the Mental Rotation Test) and flight training performance for 1,939 United States Air Force Undergraduate Pilot Training (UPT) candidates.

Performance on the Mental Rotation Test was not related to completion of training, but was related to a recommendation for specialized training after UPT. Pilot candidates who made quick, consistent, and accurate judgments were more likely to be recommended for fast-jet training (Fighter-Attack-Reconnaissance or FAR). This was consistent with the current practice of selecting the best-performing student pilots for follow-on training in FAR aircraft.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION
22a. NAME OF RESPONSIBLE INDIVIDUAL Nancy J. Allin, Chief, STINFO Office	22b. TELEPHONE (Include Area Code) (512) 536-2876 · 22c. OFFICE SYMBOL AFHRL/TSRE

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

AFHRL Technical Paper 86-70 July 1987

SPATIAL ABILITY AS A PREDICTOR OF FLIGHT TRAINING PERFORMANCE

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This publication is primarily a working paper. It is published solely to document work performed.

SUMMARY

Spatial ability is one of several cognitive/perceptual abilities that have been linked to flying performance. To examine the relationship between spatial ability and flight training performance, 1,939 United States Air Force pilot candidates were given a Mental Rotation Test prior to entry into Undergraduate Pilot Training (UPT). Contrary to common notions about this test, performance on this task was not affected by the type of paired images (same or mirror) or angular difference between the images. Performance on the Mental Rotation Test was not related to pass/fail measures from UPT, but was related to a recommendation for post-UPT training. Pilot candidates who made quick, consistent and accurate test responses were more likely to be recommended for fast-jet training (Fighter-Attack-Reconnaissance or FAR). This was consistent with the current practice of selecting the best-performing student pilots for follow-on training in FAR aircraft. Implications for pilot selection and classification are discussed.

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PREFACE

This work was completed under Work Unit 77191845 in support of a Request for Personnel Research (RPR 78-11, Selection for Pilot Training) submitted by training program managers. This paper is intended to serve as an interim report regarding one of the cognitive/perceptual tests of the Basic Attributes Tests (BAT) battery.

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I. INTRODUCTION

Spatial ability is required to a great extent in performance of a variety of tasks, including many military enlisted jobs (Carter & Biersner, 1982) and piloting aircraft (Egan, 1978; Leshowitz, Parkinson, & Waag, 1974). This paper examines the relationship between performance on the Mental Rotation Test, a spatial ability task developed by Shepard and Metzler (1971), and flight training performance for United States Air Force (USAF) Undergraduate Pilot Training (UPT) candidates.

Lohman (1979) suggested that it may be useful to distinguish among three aspects of spatial ability: (a) moving the "mind's eye" to a new perspective, (b) rotation and related transformation of mental images (spatial transformation or spatial relations), and (c) complex alteration of the object in the mind's eye (folding or distortion of the image). The Mental Rotation Test is designed to measure the second type of spatial ability; that is, spatial transformation. This aspect of spatial ability has been singled out for study most often by cognitive psychologists because it has a simple theoretical basis (Cooper & Shepard, 1978) and because general spatial ability is closely related to the ability to rotate mental images (Poltrock & Brown, 1982).

This paper examines whether spatial ability as measured by the Mental Rotation Test is related to performance in flight training. Currently, most candidates for flight training in the USAF are selected, in part, based on their composite scores on the Air Force Officer Qualifying Test (AFOQT). The AFOQT has five subscales: Quantitative, Verbal, Academic (quantitative and verbal combined), Navigator-Technical, and Pilot. The AFOQT-pilot composite score is the one most closely related to performance during pilot training and is used in the selection of pilot candidates. The AFOQT-pilot composite score is determined from scores on several subtests, including verbal analogies, mechanical and instrument comprehension, scale and table reading, electrical maze, block counting, and aviation information.

The predictive utility of performance on the Mental Rotation Test in regard to flight training performance was examined when used alone and when used in combination with current selection criteria (AFOQT-pilot composite score).

Subjects who were high in spatial ability were expected to perform better on the flying performance criteria; i.e., subjects with quicker reaction times and higher degrees of accuracy should be more likely to be successful in flight training. Further, these differences should be better reflected in flying performance scores, which have a broader range than dichotomous final outcome criteria (e.g., UPT pass/fail). The fact that the UPT pass/fail rate is unevenly distributed (80% pass rate) also makes that criterion less sensitive.

II. METHOD

Subjects

The subjects in this study were 1,939 USAF officer candidates targeted for UPT. They were tested on the Mental Rotation Test along with other tests in an experimental computer-administered test battery (the Basic Attributes Tests or BAT) prior to entry into UPT. Only subjects that had scores on both the Mental Rotation Test and the AFOQT were included in the regression analyses that predicted flight training performance (UPT pass/fail, N = 526; recommendation for follow-on training by the Advanced Training Recommendation Board (ATRB), N = 412; check flight scores, N = 133 [see below]).

Procedure

Subjects were presented sequentially (interstimulus interval = 1.5 seconds) with pairs of letters and asked to make speeded same-different judgments. The letter pairs were either identical letters or mirror images, and the letters were either in the same orientation or rotated in space relative to each other. The second letter was oriented at one of four rotations relative to the first: 0, 60, 120, or 180 degrees. The stimulus pairs were presented to the subject on a cathode-ray tube (CRT). The subject was seated about 2 feet from the display and entered a response on a data entry keypad. The subject was instructed to press a button marked "yes" if the two stimuli were identical or another marked "no" if they were not (i.e., mirror image). There were three blocks of trials, with 24 trials each. The time required to complete this test was about 20 minutes.

In order to perform the experimental task, the subject had to form a mental image of the first letter and perform a point-by-point comparison with the second. Further, when the letters were rotated with respect to one another, the subject had to mentally rotate the mental image into congruence with the second letter before making the comparison. Reaction time and accuracy of response were recorded on each trial.

According to Shepard and his colleagues (Cooper & Shepard, 1973; Metzler & Shepard, 1974; Shepard, 1975), the amount of time required to decide whether the two letters are identical or mirror images is a linear function of the number of degrees of rotation required to bring the letters into congruence. The slope of this linear function is considered to indicate the speed with which the subject performs the mental rotation, and the intercept indicates the speed with which the other processes involved in making a response are performed.

Performance Criteria

The UPT final outcome was assigned at the completion of UPT and was recorded as a dichotomous variable (pass = 1 and fail = 0). Upon completion of UPT, those students who passed received a follow-on training recommendation for either a fast-jet (Fighter-Attack-Reconnaissance or FAR) or a slower aircraft (Tanker-Transport-Bomber or TTB) by an ATRB (FAR = 1 and TTB = 0). Generally, FAR aircraft are considered to be more demanding than TTB aircraft, and better students receive a FAR recommendation. UPT final outcome and ATRB recommendation were determined, in part, by a student's performance on six check flights during UPT. A check flight involved an in-flight performance evaluation by an Instructor Pilot. The first three check flights took place in a T-37, a low-performance jet trainer. Three later flights took place in a T-38, a high-performance supersonic jet trainer. The T-37 check flights included: Mid-Phase Contact, a student's first check flight; Contact, in which the student's ability to perform maneuvers and aerobatics by visual cues from outside the plane was evaluated; and Instrument, in which the student was required to perform maneuvers by reference to the display on cockpit instruments. The T-38 check flights, in addition to Contact and Instrument, included evaluation of the student's ability to fly in Formation with other aircraft. Each student received an overall check flight grade (1-unsatisfactory, 2-fair, 3-good, or 4-excellent) and a percentage grade (based on performance of certain maneuvers within the flight) for each check flight that was completed during training. The check flight percentage scores are not linear transformations of the four-point check flight grades. The four-point check flight grade reflects the Instructor Pilot's evaluation of a student compared to all other pilot candidates at the same point in training. In contrast, the percentage grade is a weighted average of the maneuver grades from a check flight. Each maneuver grade is multiplied by a weight determined by Air Training Command. These weighted products are summed, and then divided by the maximum score possible (points received/points possible). This quotient is multiplied by 100 to place the percentage score on a 100-point scale.

III. RESULTS AND DISCUSSION

Mental Rotation

Descriptive Measures. Table 1 presents the percent correct and mean response time for correct responses as a function of whether the letters were the same or mirror images and the amount of angular difference between them. As can be seen from the table, each stimulus condition was not presented an equal number of times; thus, all composite means were weighted by the number of trials per condition. The overall percent correct was 91.8%. This was encouraging, as the common procedure with tests of this type is to calculate response times using only those trials with correct responses. Accuracy was slightly lower when the letters were the same as opposed to mirror images (91.6% versus 92.1%, respectively). Accuracy was not related linearly to angular difference (0 degrees = 93.1%, 60 degrees = 92.4%, 120 degrees = 89.9%, 180 degrees = 93.0%). These results are in direct contrast to those reported by Shepard and others (Poltrock & Brown 1984; Shepard, 1975; Shepard & Metzler, 1971).

Table 1. Mental Rotation Test: Percent Correct and Response Time as a Function of Angular Difference and Same-Different Judgment

Stimulus condition	Angular difference (degree)	Number of trials	Percent correct	Response time (ms.) Mean	SD
Same	0	6	92.7	962	329
	60	6	92.0	860	345
	120	15	85.7	1,025	357
	180	9	91.9	985	438
Different (mirror)	0	6	93.5	967	405
	60	6	92.8	1,042	360
	120	15	94.0	1,020	319
	180	9	94.0	995	315

Note. Number of subjects = 1,939.

The mean response times for correct responses are presented in Table 1 and Figure 1 as a function of same or different judgments and amount of angular difference. Type of image was not related to response time (same = 977 ms, different = 1,007 ms; $F(1,1937) = 0.60$, n.s.). The results of the analysis of variance for the mean response times are presented in Table 2. Further, as demonstrated by Figure 1, there was a significant interaction between type of image and angle of rotation, although this was due entirely to the difference in response times for the 60-degree angle of rotation for same and different judgment trials.

The correlation between response time and angle was low for both same (r = .001) and different judgment trials (r = .054). These results suggest that the model proposed by Metzler and Shepard (1974) may not provide a good description of subject performance. That is, due to the lack of a linear relationship between angle of rotation and response time, it would have been inappropriate to calculate linear regression slopes and intercepts to represent the efficiency of mental rotation and the latency of processes that do not depend on spatial orientation.

One possible explanation for these results is that the pilot candidates in the present effort had a great deal of experience with spatial abilities tasks. Many of them were natural science or engineering majors in college. Also, they had been selected for pilot training, in part, based on performance on the AFOQT, which includes measures of spatial ability.

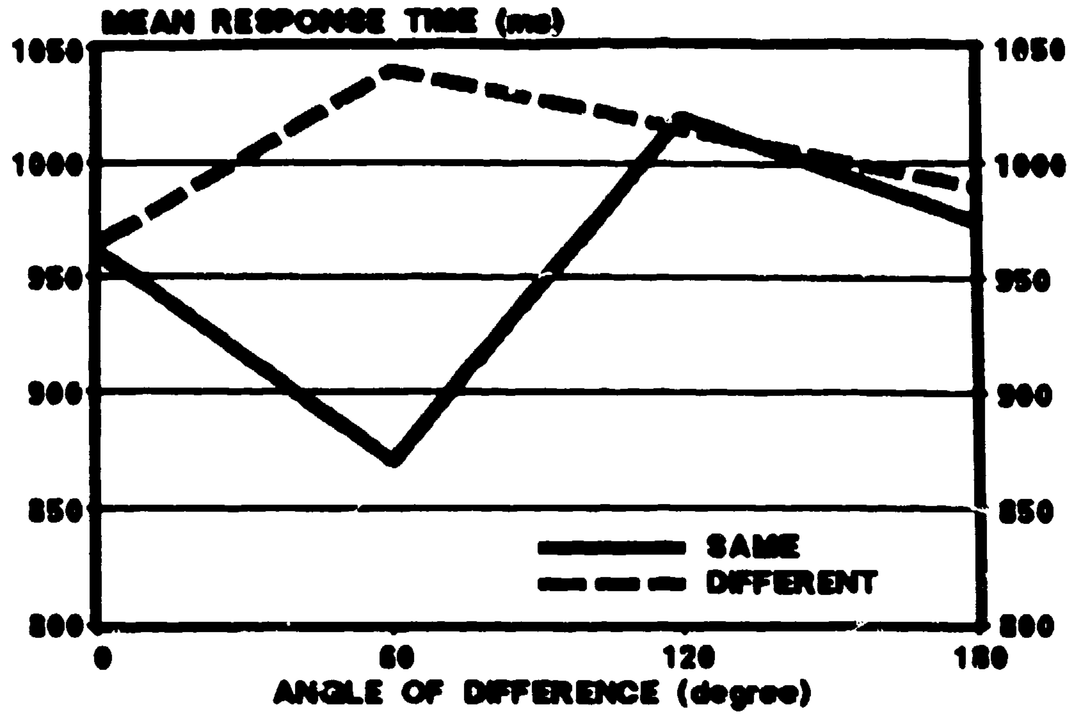

Figure 1. Mental Rotation Test: Mean Response Time as a Function of Angle of Rotation and Same-Different Judgment.

Table 2. Mental Rotation Test: Summary of Analysis of Variance

Source of variation	Sum of squares	DF	Mean square	F
Type of Judgment	4,597	1	4,597	0.60
Error	148,420,000	1,937	7,662	

Factor Structure. The most conceptually important measure provided by the Mental Rotation Test was mean response time for correct responses. A factor analysis was performed on the means for the eight combinations of angle of rotation (0, 60, 120, or 180 degrees) by type of judgment (same or different) in order to evaluate the test's internal consistency. As can be seen in Table 3, the inter-item correlations were moderate to strong (.397 to .819). The factor analysis results are shown in Table 4.

Table 3. Mental Rotation Test: Inter-Item Correlation Matrix

Stimulus condition	Same 0	Same 60	Same 120	Same 180	Mirror 0	Mirror 60	Mirror 120	Mirror 180
Same 0	1.000							
Same 60	.708	1.000						
Same 120	.663	.635	1.000					
Same 180	.580	.587	.654	1.000				
Mirror 0	.507	.497	.509	.397	1.000			
Mirror 60	.498	.492	.576	.514	.489	1.000		
Mirror 120	.633	.633	.713	.637	.563	.725	1.000	
Mirror 180	.482	.643	.782	.635	.571	.680	.819	1.000

Note. N = 1,939.

Table 4. Mental Rotation Test: Summary of Factor Analysis

Variable	Communality	Factor loadings
Same 0	.6116	.7820
Same 60	.5859	.7655
Same 120	.6838	.8269
Same 180	.5331	.7302
Mirror 0	.3983	.6311
Mirror 60	.5235	.7235
Mirror 120	.7788	.8836
Mirror 180	.7914	.8869

Factor	Eigenvalue	% of Explained Variance
1	5.27	100.0

Note. N = 1,939.

The factor analysis yielded one principal factor which accounted for 65.9% of the total variance. This was interpreted as additional evidence that for these subjects, angle of rotation and type of judgment were not related significantly to performance on this task. Because the stimulus conditions were not related to reaction time, the response times were reduced to a single score for each subject. A regression model consisting of mean response time, standard deviation of response time, and percent correct was used to predict flight training performance. These measures were chosen to reflect three important characteristics of spatial ability: speed, consistency, and accuracy of spatial transformation.

Inferential Measures. As was stated previously, the current selection procedure for pilot candidates relies heavily on the AFOQT-pilot composite score. A series of regression analyses was performed using AFOQT-pilot composite score alone to predict flight training performance, to provide a baseline by which to judge the predictive utility of scores on the Mental Rotation Test.

As can be seen in Table 5, the AFOQT-pilot composite score showed a significant but relatively low relationship with both UPT final outcome (r = .120, $p \leq .05$) and ATRB rating (r = .140, $p \leq .05$) but was not related consistently to check flight performance. Subjects with higher AFOQT-pilot composite scores were more likely to pass training and receive a FAR recommendation.

As can be seen in Table 6, the Mental Rotation model was not related to UPT final outcome (multiple R = .060, n.s.) but was related significantly to ATRB rating (multiple R = .225, $p \leq .001$). Subjects who made quick, consistent and accurate responses on the Mental Rotation Test were more likely to be recommended for advanced training with FAR aircraft. This result is compatible with the current practice of the ATRB which is to recommend the best-performing pilot candidates for the FAR track. Zero-order correlations between variables in the Mental Rotation model and the UPT outcome criteria were tested for significance only if the multiple correlation for the model was significant.

The Mental Rotation model was not related consistently to performance on the check flights. The strongest relationships occurred on the T-37 Instrument check flight grade (multiple R = .219, $p \leq .10$) and percentage score (multiple R = .313, $p \leq .01$), the T-37 Mid-Phase Contact percentage score (multiple R = .230, $p \leq .10$), and the T-38 Formation percentage score (multiple R = .244, $p \leq .10$).

Table 5. AFOQT-Pilot Composite Score: Summary of UPT Regression Analyses

Outcome measure	N	Outcome measure Mean	Outcome measure SD	AFOQT-Pilot Mean	AFOQT-Pilot SD	r
UPT (pass/fail)	526	0.78	0.41	72.1	18.0	.120*
ATRB (TTB/FAR)	412	0.60	0.49	73.2	17.5	.140*
T-37 midphase contact grade	133	2.50	1.20	70.6	19.5	.127
T-37 contact grade	132	2.95	0.94	70.8	19.4	.129
T-37 instrument grade	130	2.95	0.98	71.1	19.2	.201*
T-38 contact grade	120	2.55	1.19	71.5	19.5	.061
T-38 instrument grade	118	2.86	1.11	71.5	19.6	.088
T-38 formation grade	116	2.83	1.01	71.7	19.7	.157
T-37 midphase contact percentage	133	84.58	9.16	70.6	19.5	.124
T-37 contact percentage	132	91.09	5.48	70.8	19.4	.175*
T-37 instrument percentage	130	91.76	7.18	71.1	19.2	.148
T-38 contact percentage	120	91.30	8.18	71.5	19.5	.140
T-38 instrument percentage	118	92.29	10.79	71.5	19.6	.012
T-38 formation percentage	116	92.47	6.50	71.7	19.7	.146

*$p \leq .05$.

Table 6. Mental Rotation Test: Summary of UPT Regression Analyses

Outcome Measure	N	Correlation with outcome: Mean RT	SD RT	% Correct	Mental rotation	AFOQT-pilot	(AFOQT-Pilot and mental rotation) combined model
UPT(pass/fail)	526	-.034	-.040	-.043	.060	.120*	.136*
ATRB(TTB/FAR)	412	-.171*	-.132	.149*	.225*	.140*	.246*
T-37 midphase contact grade	133	-.114	-.025	.119	.191	.127	.212
T-37 contact grade	132	.023	-.002	.141	.142	.129	.181
T-37 instrument grade	130	-.137	-.215	-.008	.219	.201*	.288*
T-38 contact grade	120	-.117	-.168	-.093	.191	.061	.197
T-38 instrument grade	118	-.165	-.139	-.090	.178	.088	.192
T-38 formation grade	116	-.150	-.134	.005	.161	.157	.206
T-37 midphase contact percent	133	-.147	-.071	.140	.230	.124	.244
T-37 contact percentage	132	.047	-.012	.185	.185	.175*	.242
T-37 instrument percentage	130	-.207	-.300*	-.090	.313*	.148	.341*
T-38 contact percentage	120	-.077	-.103	-.052	.115	.140	.178
T-38 instrument percentage	118	-.085	-.085	-.060	.104	.012	.104
T-38 formation percentage	116	-.088	-.022	.182	.244	.146	.266

*$p \leq .05$.

These results were consistent with those from a previous analysis of three simple cognitive/perceptual tests from the BAT (Carretta, 1987). Performance on those tests also was related most closely to ATRB rating and T-37 Instrument check flight performance. The relation among the Mental Rotation Test, the other three cognitive tests, and the T-37 Instrument check flight performance was not surprising, as the Instrument check flight reflected the pilot's ability to perform maneuvers by reference to the display on cockpit instruments. Performance on the BAT tests was also somewhat dependent on the subject's ability to respond to visually displayed images on a CRT.

A Combined Model

A series of analyses was performed to determine whether scores from the Mental Rotation Test were able to improve the prediction of flight training performance beyond that provided by the AFOQT-pilot composite score alone. As shown in Table 6, a combined model that included AFOQT-pilot composite score, mean response time, standard deviation of response time, and percent correct was related significantly to both UPT outcome (multiple $\underline{R}$ = .136, $\underline{p} \leq .05$) and ATRB rating (multiple $\underline{R}$ = .246, $\underline{p} \leq .0001$). Compared to the AFOQT-pilot composite score alone, the combined model was not related more closely to UPT outcome (F (3,521) = 0.72, n.s.), but was related significantly better to the ATRB rating (F (3,407) = 5.91, $\underline{p} \leq .01$).

The combined model was related significantly to the T-37 Instrument grade (multiple $\underline{R}$ = .288, $\underline{p} \leq .05$) and T-37 Instrument percentage score (multiple $\underline{R}$ = .341, $\underline{p} \leq .05$). Compared to the AFOQT-pilot composite score alone, the combined model was not related more closely to T-37 Instrument grade (F (3,125) = 1.93, n.s.), but was related significantly better to T-37 Instrument percentage score (F (3,125) = 4.45, $\underline{p} \leq .01$), as shown in the last column of Table 6.

The results suggested that spatial ability scores may not be useful as selection criteria for entry into pilot training. However, once pilot candidates have been selected for training, spatial ability scores may be useful for early classification of pilot candidates into specialized training tracks (Specialized Undergraduate Pilot Training or SUPT).

The Air Force plans to transition to SUPT in 1991 as its primary method of training pilots. The goal of SUPT is to move the ATRB decision forward so that it occurs before T-38 training. Students could then be trained on mission-specific (FAR or TTB) skills prior to graduation. If this can be done without increasing attrition during advanced training, the cost of training will be reduced as TTB candidates would not need to go through T-38 training. Early classification also would be useful in situations where only TTB- or FAR-rated candidates are needed (Euro-Nato Joint Jet Pilot Training or ENJJPT; Air National Guard).

IV. CONCLUSIONS

Contrary to the findings of Shepard and his colleagues, response time on the Mental Rotation Test was not a linear function of angular difference of rotation and was not affected by the type of image presented.

Scores on the Mental Rotation Test were not found useful for predicting successful completion of UPT, but were shown to be related to a post-UPT advanced training recommendation. It appears that spatial ability becomes more important in the later stages of training, when pilot candidates are being classified into either a TTB or FAR track. If performance on the Mental Rotation Test was used to make an advanced training decision at an earlier stage, without increasing attrition during advanced training, training costs could be reduced in that T-38 training would not be necessary for TTB-rated candidates. Also, programs that require only TTB- or FAR-rated pilots, such as ENJJPT or Air National Guard, would benefit by an earlier track recommendation.

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